LASER TECHNOLOGIES APPLICATION TO CONSTRUCTION

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Abstract

Discovery on this subject focused on applied computer technology between the main construction office and the project field office - information flow (via Hypermedia), cost control, and program management. New research focus looked to improve finite element, and more importantly, objective data collection and machine control by applying portable laser technologies at the project site and linking collected computer data between the field office and the work center supervisor/foreman. This real time data allows managers to immediately realize optimal productivity concentration areas at the project site. Resultant data linked to Global Positioning System (GPS) technology allows for real-time, three-dimensional (3-D) site picture/modeling. Further, laser measuring and control devices applied to construction equipment permits exact cuts/grading, increases productivity (bcy/hr), saves labor, and when combined with night vision technology allows for night operations. Limited cost-benefit ratio research shows a relatively low initial investment can produce gains up to 9 times during the first year. In addition to the short-term financial gain, the reliance and consistent use of this technology improves the competitive edge for any firm that employs such and effort.

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Introduction

For years, the construction industry has been the brunt of jokes among the general public. The latest edition of "The Jobs Rated Almanac" ranks the job as construction worker 247^{th} out of 250 possible career choices, ahead of only fishermen, lumberjacks and oil field laborers. This negative perception may be from the construction industry's inability to effectively forecast, plan and react to the dynamic nature of the processes involved results in poor reputation, excessive costs, and late completion. Data collection and data management are difficult due to the varied and often unique activities that comprise each project.

Generalizing, construction management tends to mainly focus on data collection processes and data management between the main construction office and the project field office. And, what remains is an informal and most often verbal exchange between the work face to and from the project field office; thus, critical project information is subject to misinterpretation several times over. This research will demonstrate the use of current technology by which objective data is transferred between the work face and field office. The current research will focus on laser technology in natural harmony with computer and night vision technology.

Issue Identification

Applying the latest laser and computer technologies to data collection and data management from the work face to and from the field office optimizes the objectivity of the processes, reduces wasted effort, and reduces excessive costs. The objective is to improve the competitive edge for construction firms.

Now, the technological beginning for this optimization potential is Hypertext. Hypertext driven data systems are everywhere. This particular advancement is what drives the easy surfing of the Internet. This process allows the user to navigate by clicking on colored text which is linked a particular data base or interactive databases. Portable hand-held personal computers (PCs) are prevalent with the computing power of a basic desktop PC. Laser scanners are widely used today from point of sale (POS), to inventory control, and to graphical scanning.

Lasers applied to construction equipment permits precise cuts/grading, increases productivity (bcy/hr), and saves labor cost. Combining night vision technology, specifically Night Vision Goggles (NVGs), with laser controlled machines will allow for productive night operations without the need for temporary lighting or portable light plants. It's time

that combination of these three items apply to today's construction jobsite.

COMPUTER AND LASER SCANNERS

Technology Gateway

Computers have enjoyed tremendous growth since 1980. The growth in this industry is best illustrated by graphs showing exponential performance growth of critical computer hardware system components. Below (Figures 1 - 3) are three graphical representations illustrating: Average CPU Speed vs. Time, Average CD-ROM Maximum Speed vs. Time, and Average Modem Transfer Speed vs. Time.

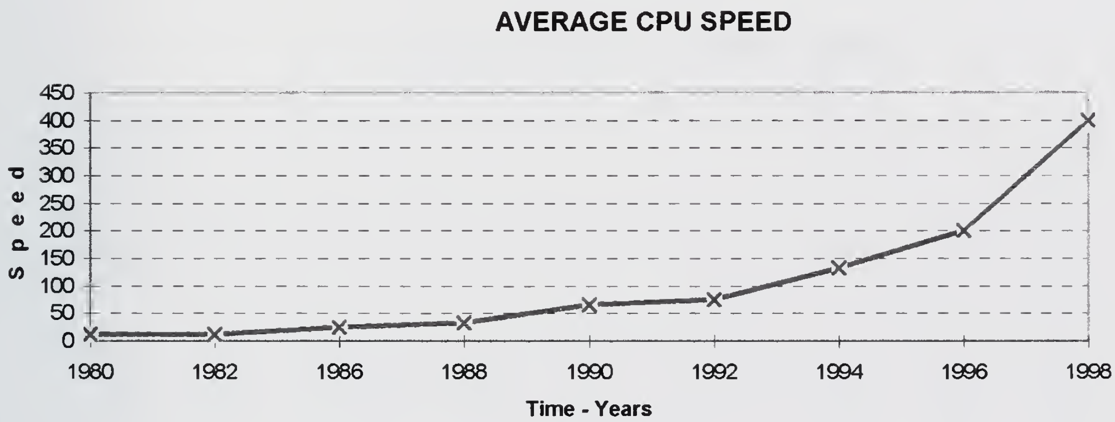

Figure 1. Most prevalent CPU speed for the specified year (Pen Computing, 1998)

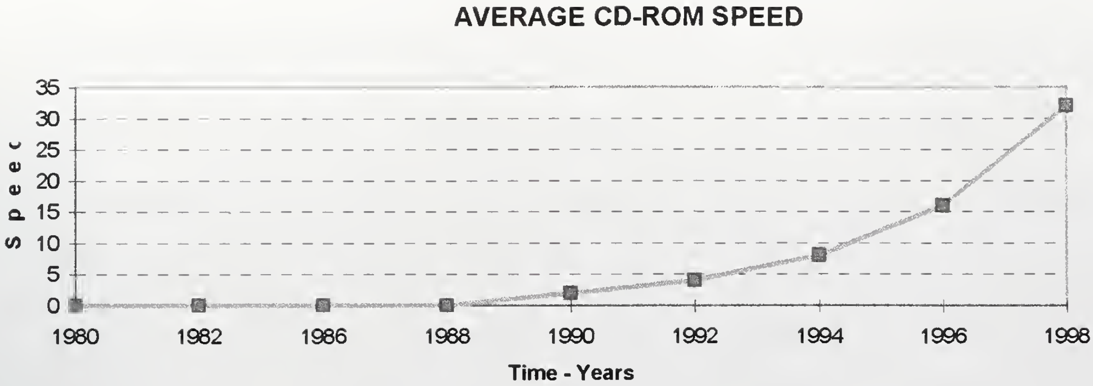

Figure 2. Most prevalent CD-ROM speed (max.) for the indicated year (Pen Computing, 1998)

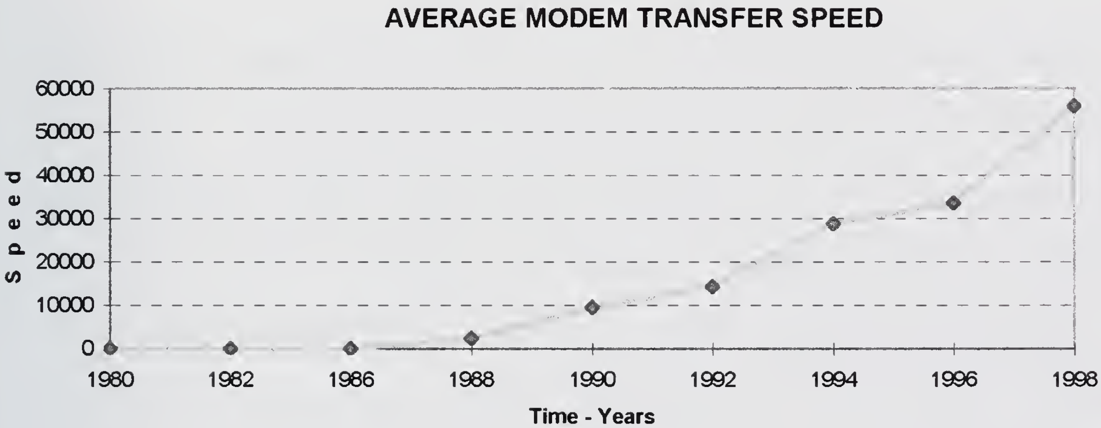

Figure 3. Most prevalent modem data transfer speeds for specified year (Pen Computing, 1998)

At issue with today's computer industry; will exponential performance growth in hardware continue? As a consequence industry growth, the computer physical size and power consumption have deceased consummately with the aforementioned hardware trends. This comparison will be discussed later. A specific development to come out of the rise of the computer age was Hypertext. In 1991, hypertext was defined as a "database system of text and graphics that allowed the reader to jump from idea to idea depending on one's interest" (Williams 1991), vice traditional reading which is linear - beginning to end. Before the Internet, hypertext was used as an interactive data access tool.

By 1993, Hypertext technology had changed dramatically. For example, the United States Navy contracted for Test and Evaluation (T&E) scope and methods for the upcoming T&E of their prototype Modular Elevated Causeway System (ELCAS-M). The Navy received a categorized hypertext program that enveloped plans and specifications with the Navy's specified performance requirements. During the actual T&E in April, 1995, an inspector assigned to the tractor trailer turntable located at the end of the constructed causeway with pier sat in a driving storm accessing, from his laptop, plans, specifications, inspection forms and photos of the turntable components. The inspector placed additional digital

pictures on completed inspection forms to document performance of the components.

Clearly, the Navy received objective data. The inspector only took some reference notes. He did not carry voluminous specifications and drawing sheets, or Navy test requirement documents. Further, the data from the T&E was analyzed and easily downloaded into the final report. The report was completed with a staff of four and ready for review two months after the test – "a remarkable productivity advance from a process that typically took a year with a similar T&E effort." (NSWC, Carderock 1995)

From here, we will make a transition into effects of computer and laser scanning technology improvement on construction productivity.

Construction Productivity

Ginger Evans, Project Manager for the Denver International Airport, and the 1998 Distinguished Lecturer, M. E. Rinker School of Building Construction, University of Florida described a similar productivity increase during a speech in November 1998. She compared the construction of the Denver International Airport (DIA) with the construction of the Dallas Fort-Worth (DFW) Airport completed 20 years prior. She stated that DIA, which was twice the size of DFW, was completed in the same construction time - representing a doubled construction productivity rate in 20 years. And, "information access and information flow critical to accelerated productivity was made possible by successive improvements made to computer capability." (Evans 1998)

During construction, DIA suffered through many communication, coordination, and scheduling problems. With 10,000 workers on site at peak construction output, task communication down to workers and communicating task completion, non-completion, or resource problems up the chain of command was verbal and therefore subjective - filtered at every level. The DIA project management computer systems focused on obtaining construction data at an intermediate level (project field office). Once in the system, the data was considered to be objective, but that

data was changed many times over from the worker to the field office. Below (Figure 4) is a typical large project information flow chart:

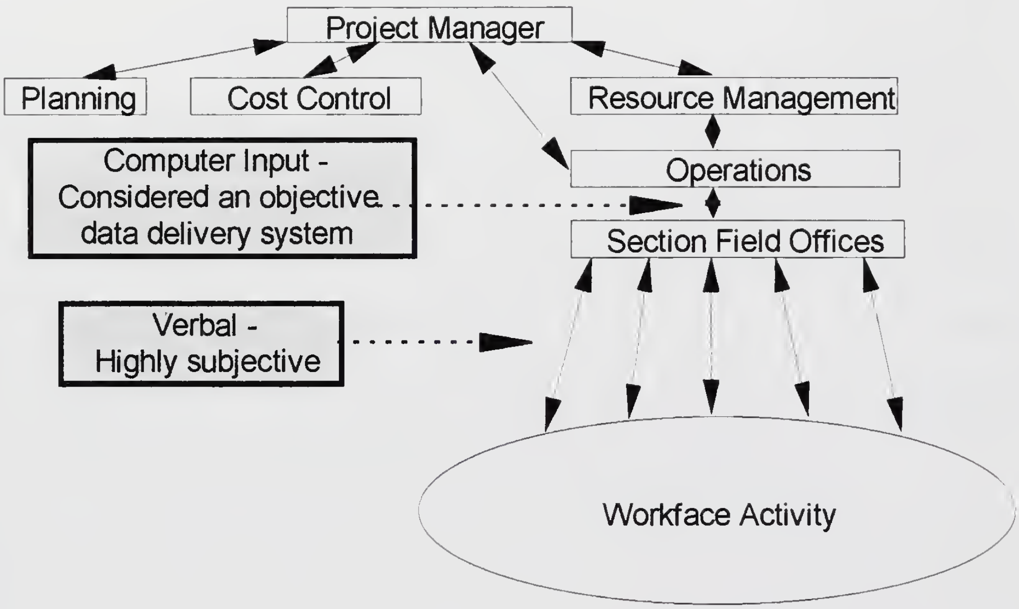

Figure 4. Information flow chart distinguishing between objective data input sources/users and subjective data input sources/users.

Driving out subjective data sources and subjective data users is the optimizing goal. This goal to drive out subjectivity is greatly helped by applying portable computing assets into the work face arena.

Today, 13-pound laptop computers of a couple of years ago have given way to 6 ounce hand-held PCs. And, a decrease in computer component power consumption coupled with lithium-ion battery technology has contributed to increased computer capability and to smaller hand-held computer sizes. With the abundance of portable micro-computing technology, the construction industry can optimize objectivity and minimize wasted effort, i.e. call back for clarification or additional information. The cost-benefits of this objective work face effort were researched to be up to 9 times the initial investment over the first year. This expected return on investment discussed in the next section.

Cost-Benefit

Research for this report revealed a recently completed a $250,000 construction project where project material cost totaled $150,000. The project manager did not realize any problems that he could control; everything proceeded according to his plan; within schedule and cost control goals. For all lumber, he ordered about 5% extra quantity for uncertainties he categorized as "waste and shrinkage." The total lumber cost was $80,000. Thus, $4,000 worth of lumber was ordered above what was required.

The project manager introduced a bar code laser scanner and mandated the uncut lumber storage area scanned once a week. The collected data showed 90% of his additionally ordered lumber ($4000) was walking off the job; and only 10% was actually waste. The project manager looked out his window and saw his lumber storage area unsecured and located 20 feet from a busy city thoroughfare. He secured the lumber area and noticed a steep drop in unaccounted lumber each week, thereafter. The cost of the bar code laser scanner was $400. The cost of project time was one person's time for 15 minutes each week (time to scan the lumber storage area). The potential savings were 90% of $4000, which equaled $3600. That potential savings represented 1.44% of the total project cost. Finally, the Cost/Benefit ratio

for this particular effort was 9. This example illustrates how objective data revealed a problem that was easily mitigated, and provided opportunity to achieve up to 9 times return on the initial investment.

The above cost-benefit example involved materials, and it is noted here that motivation for optimizing the project was not self-actuated by the project manager (PM) - the PM was told of this savings potential.

The following example examines the benefit from objectively reported productivity on a linearly scheduled paving project in Puerto Rico. Due to the island setting, the equipment asset quantities were fixed. The project consisted of pothole replacement then a 3½-inch overlay over a 40 foot-wide existing highway for 8 miles. While the politically set completion date was obtainable at the beginning of the project, two weeks of rain at start up required the schedule to be compressed.

Initially, the recorded overlay production rate was 1 mile per day. The overlay rate soon slipped to 0.75 mile/day due to a workday change from 10 hours/day to 15 hours/day. Consequently, after working for 6 days in a row, the overlay rate dropped to 0.65 miles per day, where it remained into the next week. No other changes were made to affect

productivity; and thus, on the last day the project was ½ mile short of completing.

Why was there error in achieving the original completion date? A lack of objective reporting of productivity information was at fault. Intuitively, the provided information did not clearly illustrate the scenario to managers. Everyone involved physically saw the production rate fall, but their subjectivity (individual and combined) meant that they could not forecast the end result of a gradually fading productivity rate. In retrospect, should the project superintendent reported production data via hand-held PC, cause of the production rate decline would be objectively and explicitly linked to more over-time per day combined with successive workdays without a day off. The objective result would have shown the completion date slipping beyond what the crew was being held to. These two examples demonstrate potential savings from applying computer and laser scanning technologies.

The Future

To some degree, Ginger Evan's DIA and DFW airport comparative construction effort presupposes exponential growth of construction productivity. But quickly, the following provides major computing milestones with corresponding construction application in selected years since 1950:

Year	Computer Age	Construction Application
1950	Big Mainframe	Complex weapons systems
1970	Initial PC development	Some construction data base management
1980	Desktop PC	Database management and manipulation, Forecasting, Computer Aided Design (CAD), and Word processing
1990	Micro-computers/Laptop	Simulation, Integrated database management, Database links, and Internet

1998 Portable Age - Hand-held PC Voice Recognition	Virtual Simulation, Digitized scanning, and imagery

The trend, shown above, illustrates portable PC type computing being pushed down to the individual on the go, in the field. More importantly, with less impact to an operating construction foreman. From cost benefit examples, the benefits can significantly out distance initial costs, plus portable computer technology cost is minuscule compared to many project cost.

Further, macro-economic philosophy supports employing portable microcomputers for innovation by supply and demand driven innovation. Construction industry professionals regarding their experience with innovative construction projects have stated that "problems" <u>drive</u> construction innovation and owner's demands <u>dictate</u> innovation (emphasis added) (Nam and Tatum, et al 1992). The aforementioned comment emphasizes and captures demand-side factors in the innovative process. The previously discussed project material cost reduction from a bar code scanner example surfaces the often neglected factor - supply-side factors affecting construction innovation. This two-factor system of construction innovation must be clearly defined to constructors in search of optimization.

From here, the research will focus exclusively on laser technologies and their application to the construction industry.

LASERS

Background

Lasers are frequently in the news. A medical report describes how they're used for delicate procedures such as repairing retinas, removing tattoos or burning tiny holes in the heart. An industrial journal reports on lasers cutting intricate shapes out of titanium. A photographer displays a collection of holograms shot with a laser he built.

In fact, lasers are used for diverse applications. The one thing these uses have in common is the need for remarkable precision. That need for precision made lasers a natural fit for surveying. Now, their use is being expanded to other construction chores. Before we examine those, let's have a quick history lesson.

Lasers were invented in 1959 when it was found that an atom in an excited state would shed a photon when struck by a photon of the same energy level as the photon it would spontaneously emit before returning to the ground state. These two photons would then provide the energy for other excited atoms to shed their photons in phase with the original photons.

Simply, imagine a pool table with the balls randomly scattered on it. Imagine a pool hall shark setting up the cue ball and hitting it so that it strikes any other ball. These two balls now go hit two others. These four strike four others. Soon every ball is in motion, and it all started with one moving ball. Now, the really remarkable thing is that a laser will put every ball in the side pocket. This process, Light Amplification by Stimulated Emission of Radiation (LASER), is what gave the laser its name. The output of a laser is light that is directional, intense, monochromatic (usually red), and coherent (the light waves are synchronized because the photons are in phase).

In the 40 years since lasers were invented, they've become cheaper, smaller and more reliable. Additionally, you can build a basic laser with parts from an electronics store or science supply house.

Figure 5, below, depicts a laser type to construction application matrix. It is from here that further discussion will proceed.

	Solid State	Gas Lasers	Semi-conductor
Laser Construction Application	Fixed Beam Laser	Rotating Beam Las	Laser Distance Measure
Surveying	X	X	X
Earthmoving		X	
Concrete Finishing	X		
Paving Operation	X		
Site Modeling (3-D)		X	X
Material Management	X		
Data Collection	X	X	X
Safety Detection (Cranes)	X		
Welding/Cutting	X	X	
Crane Operation	X	X	

Figure 5. Laser Type to Construction Application Matrix

Note: Safety Detection (cranes), Welding/Cutting, and Crane Operation applications will not be discussed.

Surveying

Surveyors have used lasers for years. The better models are accurate to within plus or minus 1/16 inch over 100 feet. A typical package includes the laser, a tripod, one or more sensors, and grade rods to hold the sensors. The laser has an internal stabilizing mechanism, called a compensation system, to make it resistant to shock and ground vibration while in use. See Figure 6 for a representative surveying component.

A new development in surveying is the use of aircraft-mounted lasers. A laser unit is attached to the underside of an airplane or helicopter and transmits its beam toward the ground.

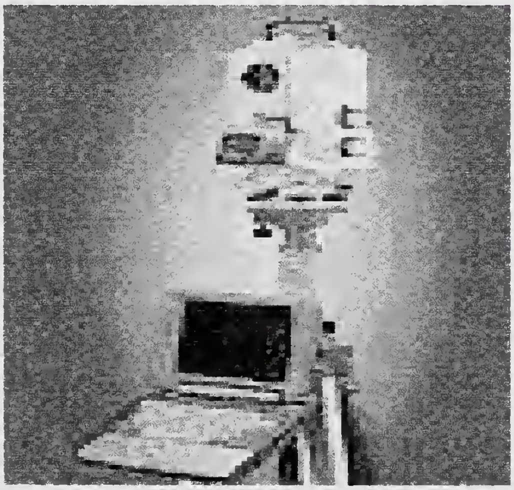

Figure 6. Typical Laser Surveying Equipment. (Trimble Navigation Ltd., 1999)

Positioning units on the ground and in the aircraft correlate each pulse point to the plane's position. A computer combines the position and laser data to produce a three-dimensional (3D) map of the ground. Accuracy is maintained via Global Positioning System (GPS) technology.

This map can show ground features, or it can include aboveground features such as trees, power lines, and buildings. Compared to traditional survey methods, the results are more precise, with survey points spaced a few feet apart and yielding 4-inch vertical accuracy. Best of all, results can be obtained in a "few hours rather than the few months it might take for a two-person survey crew." (TOPCON Laser Systems, 1999)

Another emerging construction application is a 3D laser scanning and modeling system. A system is currently being developed by Cryra Technologies, Incorporated. A portable, auto-scanning laser and PC system allows collection of up to 800 as-built points per second from surfaces up to 110 yards away. Collected points are immediately converted, via system's software, in to a 3D model with an accuracy of 1/50th of an inch. The system's software allows collected data to be exported to popular CAD and rendering software. The innovative, pulsed laser (eye-safe, Class II), has

advantages over conventional fixed-beam lasers. First, the high power of each pulse allows the operator to conduct a survey without the use of targets or reflectors. Part of the emitted laser energy is naturally reflected back to the instrument by the object being measured, even for surfaces not perpendicular to the incident laser beam. This reflector-less aspect also allows for measuring objects that are inaccessible, such as mine walls or suspended mechanical system components, or for hazardous locations like highways, airports, and hazardous waste/materials where disruption to operation is eliminated.

Concrete and Paving Screeds and Finishers

A common application for laser technology is concrete finishing and paving operations. Somero Enterprises, Houghton, Michigan, claims their Model S-240 laser screed can place up to 50,000 square feet of concrete a day or 240 square feet in a single, one-minute pass. At best, it is estimated that a crew with a 48-inch diameter machine finisher can complete 32,000 square feet per day. (Walker, 1986) The productivity increase of the laser-placing machine is 38%. Additionally, the end result is a flatter floor. Figures 7 and 8 illustrate floor flatness (FF) measured in inches over the plane surface in yards. While the floor profile deviations of ½-inch over 10 yards for a hand screed floor appear to be insignificant, created demand for near perfect floor flatness will occur. Perhaps certain computer of electronics manufacturing companies could produce faster and produce a better quality product resulting from a near perfectly level concrete slab. Figure 9 shows a typical laser controlled screed.

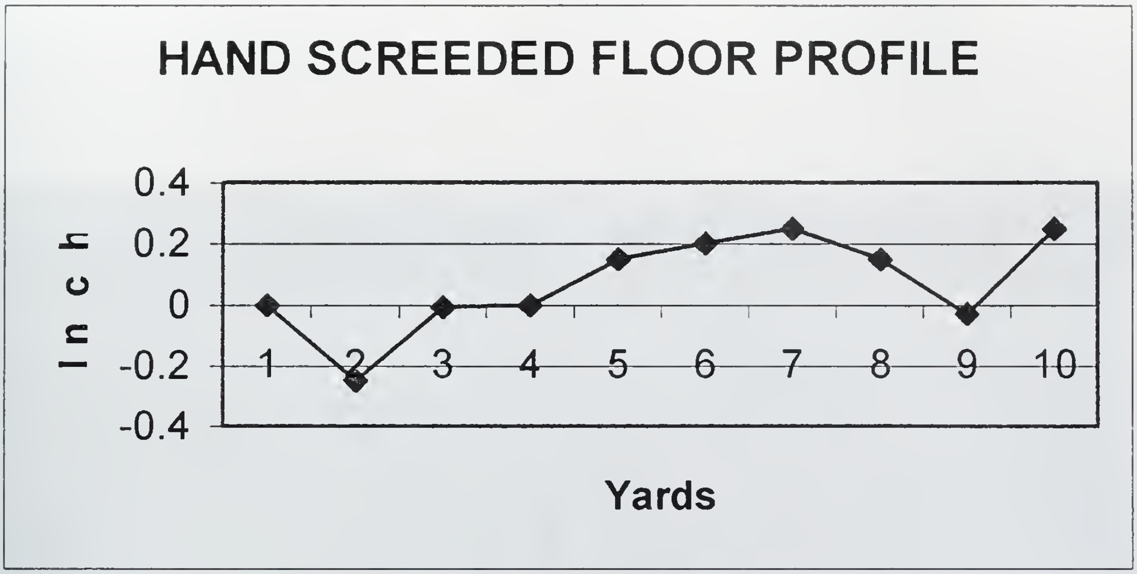

Figure 7. Hand Screed Floor Profile - deviation in inches over plane measurement in yards. (Laser Screed Ltd., 1999)

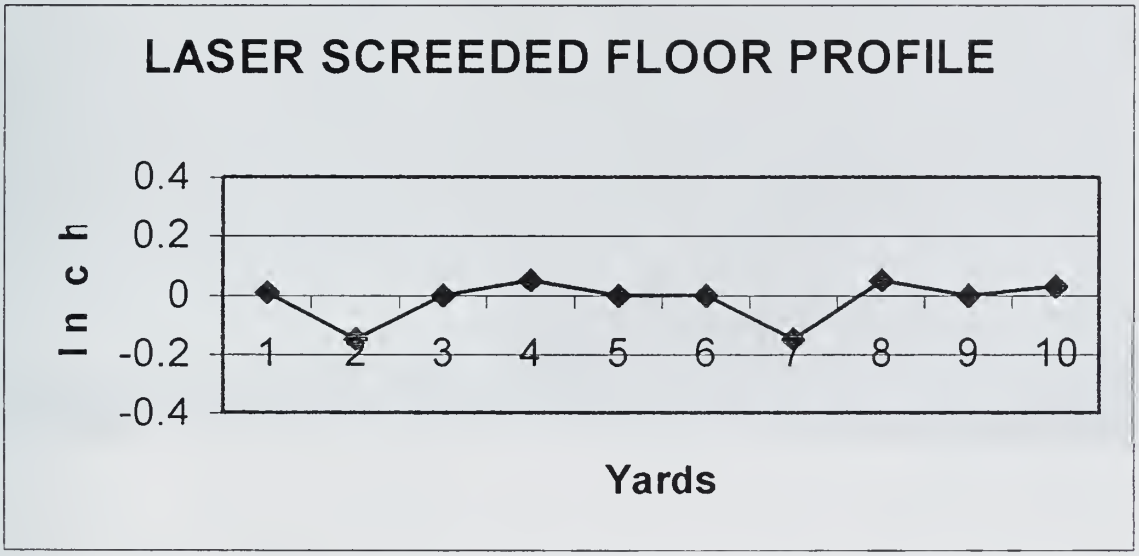

Figure 8. Laser Screed Floor Profile - deviation in inches over plane measurement in yards. (Laser Screed Ltd., 1999)

For the average wear surface or where the concrete slab is to be covered by another material like tile, carpet, or wood, the value of a laser screeded surface is not warranted.

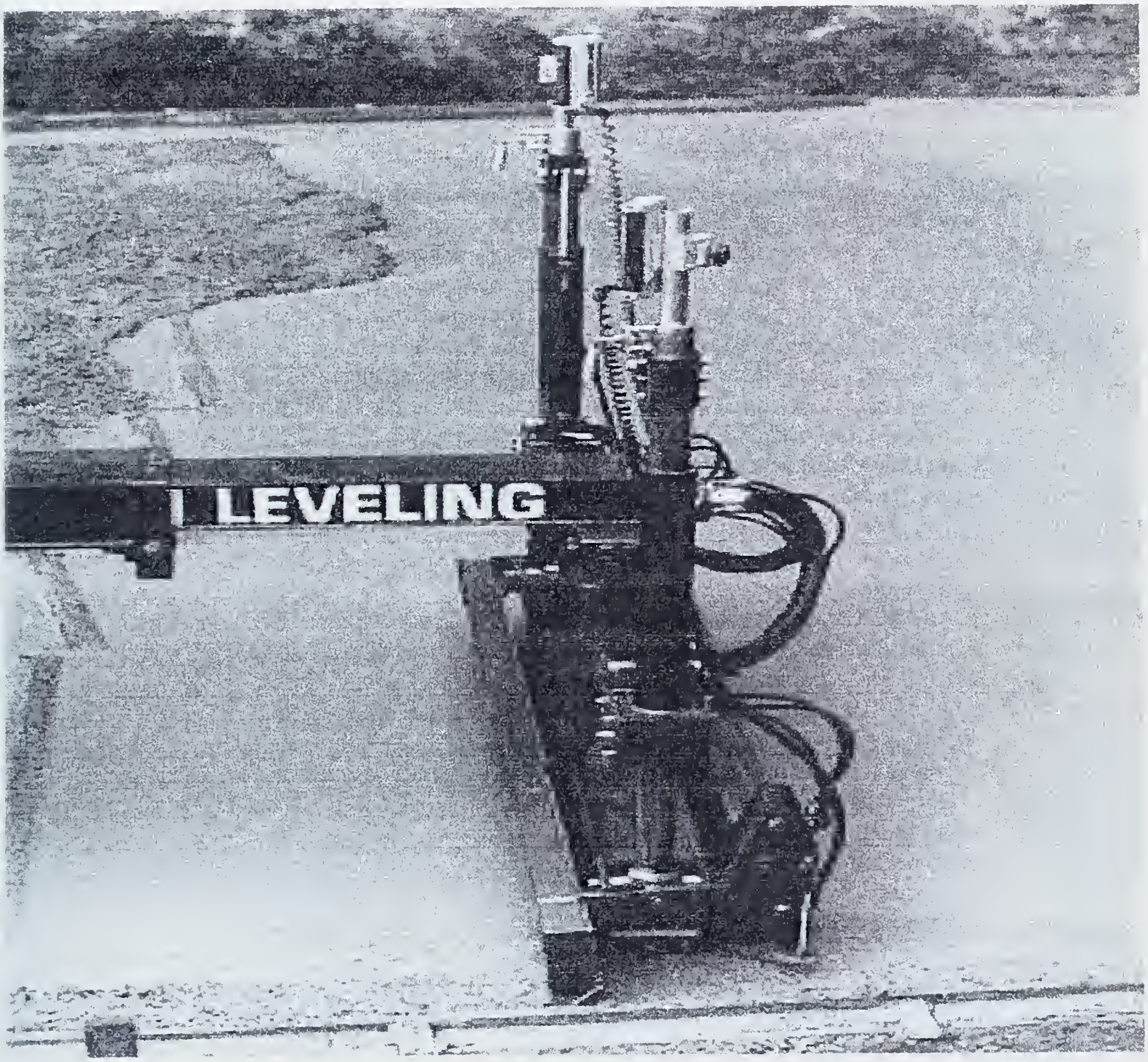

Figure 9. Laser Actuated Leveling Concrete Screed. (Laser Screed Ltd., 1999)

Application for pavement (asphalt and concrete) is much different than structure slabs, as users travel over the finished surface at high speeds. The surface imperfections in the pavement are transferred to the user through via the vehicle suspension system. Laser screed use in pavement construction mitigates the surface smoothness distortion that the driver would experience. Intuitively, a reduction in pavement surface distortion would result in reduced maintenance cost for both the roadway owner and the vehicle owner.

Construction Machinery and Equipment

The laser's accuracy also makes it useful for machine control. Graders, scrapers and excavators can use lasers to maintain tight tolerances. The other significant importance of laser controlled machines is productivity rate increase. "If a small contractor puts on a grader control system and gets and additional 50% worth of productivity, then he is not going to let that grader sit around for half the year." (McGarry, 1996) With the grader control system, a grade checker is eliminated and, under the right conditions, grading can be accomplished in 3rd gear. "The initial price can scare the devil out of some people considering a laser system. But, if you're laying down five miles of road and your operator is off his grade by ½-inch for the entire five miles, it will mean that much more rock or pavement to reach grade." (Harris, 1996) Before the research continues with exciting productivity gains, the research must focus on the detailed workings of such systems.

Machine control can be either fully automatic or manual. In manual mode, the system relies on the operator to make adjustments in response to lights on the laser sensor that indicate above, below or at grade. Fully automatic systems connect to the machine's hydraulic system and send electronic signals that prompt the machine to automatically

make adjustments to proper grade or depth. Figure 10 illustrates a fully automatic laser control system applied to a typical excavator. Figures 11 and 12 illustrate manual laser control systems applied to a typical bulldozer and grader, respectively.

Figure 10. Fully Automatic Laser Controlled Components on a Typical Excavator. (Topcon Laser Systems, 1999)

Figure 11. Conventional Bulldozer Outfitted with Manual Laser Control Device (Topcon Laser Systems, 1999)

Figure 12. Manual Grader Laser Control System (TOPCON Laser Systems, 1999)

Do lasers have limitations? Yes, while they can handle any slope found in common site prep, and even dual slopes, they are still confined to flat planes. If your site has a curve or crown, lasers won't work. And although they're reasonably durable, they're not hammer-proof. If a laser

and a sledgehammer get knocked together in the bed of a pickup truck, the laser loses.

Another question to ask, is how well lasers will perform compared to emerging technology, such as Caterpillar's Computer Aided Earthmoving System (CAES)? Caterpillar hopes their development will “revolutionize” the mining industry. CEAS is part of Cat Mining and Earthmoving Technology (CMETS) which integrates advanced communications (wireless and GPS technology), machine monitoring, diagnostics and positioning, job and business management software, and machine control. If the day comes where machines are mere robots controlled by an elaborate system of computers and satellites, where the operator only observes the work from a tower with one hand poised over a kill switch, lasers will be decidedly old-tech.

For now lasers offer incredible precision and, in the right application, they can increase production exponentially. To think, all this because 40 years ago some scientists were playing around with nervous atoms.

NIGHT VISION TECHNOLOGY

Night Vision Goggles

The use of Night Vision Goggles enhances one's ability to see into the night. The un-aided eye operates within the visible light spectrum and thermal imagers operate within the infrared spectrum. Night Vision Goggles operate in the visible light and near infrared spectrum, allowing one to see both amplified visible light and the near infrared. Night Vision Goggles allow pilots and observers to use the most important aviation asset available (increased visual acuity) to see in a low light environment, effectively allowing aircrews to see in the dark with their own eyes.

There exists a misconception that one's vision is restricted when using Night Vision Goggles (NVG) due to the current technology 40-degree field of view limit. Consider that the normal unaided eye has a visual acuity of 20-200 at night. In most states, this is classified as legally blind. Therefore, continuing with the aircrew, members "have approximately a 200 degree un-aided field of view at night, they are flying with visual acuity classified as ***legally blind.*** Given this information, if aircrews are not employing NVG's they should, at a minimum, be basic instrument flight *proficient* in order to conduct night

flight operations with the greatest margin of safety." *(Skycop, 1999)*

Because NVG's allow un-aided peripheral vision as well as vision underneath the goggles, aircrew members *are not* decreasing their field of view. In fact, by properly using NVG's, those same aircrew members have added 40 degrees of 20-40 vision to their 200 degrees of 20-200 vision.

More importantly, by employing proper scanning techniques while using NVG's, aircrew members can actually increase the area of 20-40 vision up to 180 degrees or more. Contrary to popular concept, Night Vision Goggles actually enhance the effectiveness of airborne searchlights, while simultaneously increasing flight safety. The intensity of the searchlight does not significantly limit acuity. With this in mind, NVGs can be used in urban environments, with high intensity light, with minimal image "washout". This allows aircrews to see into dark areas such as alleys, between buildings, parks, shorelines, and areas that otherwise cannot be seen using the unaided eye. NVGs are affected by "green" light, which appears as a bright blotch.
Military operations with NVGs show best visual acuity with blue or red light sources. Red is recommended for markers or guides, as a person's natural night vision is not affected by red light. Un-aided night vision is interrupted

for some time after exposure to other colored light and white light. (U. S. Army, 1996)

Earthwork at Night

The Navy’s expeditionary construction experts, Seabees, have been experimenting with operating heavy construction equipment at night. Such night operations traditionally offered little incentive due to significant losses in productivity. Figure 13 is a picture of a small arms firefight at night, where the distance from weapon to target impact is 1200 yards. The distance is hard to discern from the figure.

Figure 13. Small Arms Night Fire. (Operation Bearing Duel, NMCB FOUR FEX, 1998)

With the advent of Night Vision Goggles (NVG's), the Navy's earthwork production and accuracy, during night operations, improved little. The complaint from the operators was that they "could not feel" what they were excavating, grading, or loading. The NVG's offer the ability to see at night, but it is at a cost - only being able to see in two dimensions like a picture. There is no depth perception. Applying laser guiding and controlling technologies to the Navy's equipment combined with the NVG's will allow the "feel" to be perceived by the operator. The addition of laser technology will allow the to operate productively at night.

Virtual Reality

The day will come when machines are mere robots controlled by and elaborate system of computers of computers and satellites; and where, the operator observes the project site from a tower with his only control on a keyboard and kill switch. Combining 3D modeling, laser controlled machines, and night vision technologies will accelerate the coming of such a day.

Just think of the many new applications that could be undertaken with that system scenario. Man doesn't like to work in extreme conditions like heat and cold, or confined and outer space. Consider that man as a labor instrument really operates efficiently at 70 degrees fehrinheight and 50% relative humidity; anything up or down and productivity exponentially decreases. (Oglesby, Et al, 1989)

Machines have a much greater range of operating conditions. Applications of advances in the aforementioned technologies can only benefit society.

Conclusion

There are papers, books, simulations, and continued research that aim to improve productivity in the construction industry. Subjectivity in data information systems derails productivity initiatives. Additionally, "problems" drive construction innovation and owner's demands dictate innovation." (emphasis added) (Nam and Tatum, 1992). Focus on applying today's laser technologies in combination with computer and night vision technologies can produce short term and tangible gains in construction productivity. However, addressing two factors drives long term success: (1) eliminate subjective database management, and (2) realize neglected supply-side innovative factors. The best opportunities for laser applications are on construction equipment and machines. Laser application on construction equipment and machines illustrates three improvement initiatives: (1) precise guiding, cuts and grading, and concrete/paving placement screeds, (2) reducing required labor, and (3) opportunities to operate at night in combination with Night Vision Goggles.

Recommendation

Further research linking cost to field application of lasers in earthwork is needed. Intuitively, it can be shown that gross earthwork productivity is better without laser controlled equipment. However, there is a point in completing an earthwork operation where the application of precise laser controlled equipment increase productivity curves versus non-controlled equipment productivity curves match. This fact must remain at the cognitive forefront for managers considering laser-controlled machines. Obviously, using machines to work where man can or will not provides wonderful opportunities to better society. It is the opportunities that will create the demand by customers.

Additionally, there is need for improvement in better linking technology research to practical application in the field. The drive to facilitate persuasive discussion using technology to the fullest extent is controlled by cost and associated risk with that cost. Maximizing thinking out of the box to optimize a firm's competitive edge as it relates to construction management works only for those companies that want to grow. Investor's and financiers assume each company ought to grow; therefore, investment in technology is viewed as a survival tool. Some may view growth in

technology industries merely leads to spillover effects into construction, but the research demonstrates tremendous private construction industry innovation is being developed. What a time to be involved in an ever dynamic era.

The following is a summary of specific recommendations specifically for the United States Navy:

- Invest in adding laser technologies to ongoing investments in night vision and computer technologies.

- The Naval Facilities Engineering Command (NAVFAC) ought to task the Naval Facilities Engineering Service Center (NFCES) with initiating Test and Evaluation (T&E) of combining laser with night vision and computer technologies.

- The Navy ought to partner with commercial Research and Development (R&D) initiatives to reduce duplicative effort.

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